Tech. B

No. 68—1914.

British Engineering Standards Association.

(Incorporated 1918.)

FORMED IN 1901 AS THE ENGINEERING STANDARDS COMMITTEE
BY
THE INSTITUTION OF CIVIL ENGINEERS.
THE INSTITUTION OF MECHANICAL ENGINEERS.
THE INSTITUTION OF NAVAL ARCHITECTS.
THE IRON AND STEEL INSTITUTE.
THE INSTITUTION OF ELECTRICAL ENGINEERS.

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BRITISH STANDARD

METHOD OF SPECIFYING

RESISTANCE

OF

STEEL CONDUCTOR RAILS.

LONDON:
PUBLISHED FOR THE ASSOCIATION BY CROSBY LOCKWOOD & SON,
7, STATIONERS' HALL COURT, LUDGATE HILL, E.C.4; AND 5, BROADWAY, LONDON, S.W. 1;
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* Succeeded the late SIR JOHN WOLFE BARRY, K.C.B., February, 1918.

BRITISH ENGINEERING STANDARDS ASSOCIATION.

The following are lists of Members of the Sectional Electrical Committee and also of the Conference on Conductor Rails responsible for the drafting of the Report on the Method of Specifying the Resistance of Steel Conductor Rails :—

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WHICH IS ALSO THE

BRITISH NATIONAL COMMITTEE

OF THE

INTERNATIONAL ELECTROTECHNICAL COMMISSION.

August, 1914.

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* Chairman, British National Committee. † Hon. Secretary, British National Committee. ‡ Since deceased.

CONFERENCE ON CONDUCTOR RAILS.

August, 1914.

Chairman, DR. R. T. GLAZEBROOK, C.B. *(Representing the National Physical Laboratory).*
Mr. F. Bisacre *(Representing Mr. C. H. Merz).*
London Brighton and South Coast Railway, Mr. Philip Dawson.
Incorporated Municipal Electrical Association, Mr. J. E. Edgcome.
Municipal Tramways Association (Incorporated), Mr. A. L. C. Fell.
Great Eastern Railway, Mr. H. W. Firth.
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District Railways, Mr. C. E. Squire.
Great Northern Railway, Mr. W. C. Thompson.
Institution of County and Municipal Engineers, Mr. H. T. Wakelam.
Midland Railway, Mr. W. B. Worthington.

The Conference has been assisted in the preparation of this Report by Mr. S. W. Melsom, of the National Physical Laboratory.

PREFACE.

Considerable inconvenience has arisen in the past owing to the existence of a certain amount of ambiguity in regard to the methods of specifying the resistance of conductor rails.

The question was brought officially to the notice of the Engineering Standards Committee in March, 1913, and it was suggested that a Conference should be called with a view of endeavouring to arrive at some general agreement as to the method to be employed in the future.

After some preliminary correspondence a Conference was held of those interested, at which a satisfactory solution was reached. It is therefore hoped that the recommendations contained in the present Report, which embody the results of that Conference, will be generally adopted and thus tend to eliminate misunderstandings in dealing with steel conductor rails.

In the Tables and Formulæ the figures are usually given only to three figures. Care has been taken, however, in rounding up the results to see that no error as great as 0·1% has been introduced and the various formulæ will be found to be consistent to within this limit.

This Report was adopted by the Sectional Electrical Committee at their meeting held on June 12th, 1914.

This Report was approved by the Main Committee at their meeting held on July 16th, 1914.

R. T. GLAZEBROOK,

Chairman of Conference on Steel Conductor Rails.

BRITISH STANDARD METHOD OF SPECIFYING THE

RESISTANCE OF STEEL CONDUCTOR RAILS.

Introductory Remarks.

It has been usual in the past to specify the resistance of steel conductor rails in terms of that of a copper rail. The method has, however, given rise to some ambiguity. The two rails are assumed to be of the same length but it has not always been quite clear whether they were to be also of the same weight or of the same volume. In the first case a comparison was made of the mass resistivities of steel and copper; in the second the comparison was between the volume resistivities. The two results differ, and difficulties have arisen from the uncertainty which has ensued.

Electrical Resistance is now measured in ohms or fractions or multiples of an ohm, and it has seemed desirable to specify a method of measuring the resistance of a conductor rail in these units.

It is clear that a given length of rail must be taken, and for this length one yard has been chosen. The resistance might be expressed simply in ohms per yard, but this would not allow of a ready comparison between the resistances of two rails of different sectional areas or of different weights to the yard. With a view, then, of permitting this comparison, it becomes necessary to express the results as the resistance of a rail of some standard dimensions, and for this purpose a rail weighing 100 lbs. to the yard has been selected.

Rails are bought and sold by weight and classified by the number of pounds per yard, and it is, in consequence, more convenient to define the standard dimensions in terms of length and weight per yard rather than in terms of length and sectional area.

British Standard Method of Specifying the Resistance.

In specifying the resistance of a steel conductor rail the value shall be given in microhms (millionths of an ohm) and shall be expressed as the resistance in microhms at a temperature of 60° F. (15°·6 C.) of a rail of the same material as the conductor rail in question having a length of one yard and a weight of 100 lbs.

Resistance of a Rail weighing W lbs. per Yard.

It follows from the above that if the resistance of a rail weighing 100 lbs. to the yard be R_s microhms, that of a rail of the same material weighing W lbs. to the yard will be $\frac{100\ R_s}{W}$ microhms.

Conversely, if the resistance of a rail 1 yard in length weighing W lbs. to the yard be R_w microhms, that of the corresponding 100 lbs. rail will be $\frac{W R_w}{100}$ microhms.

In either case we have the relation

$$100 R_s = W. R_w.$$

Temperature Coefficient of Conductor Rails.

For the purpose of reducing observations made at temperatures other than 60° F., to the standard temperature, a mean coefficient of increase of resistance with temperature of 0·26 per cent. per 1° F. (0·47 per cent. per 1° C.) shall be employed unless otherwise specified.

Where greater accuracy than this is required for a wide range of temperature the temperature coefficient of the actual piece of rail should be determined.

NOTE.—The temperature coefficient of the conductor rails tested at the National Physical Laboratory for the purpose of this Report varied from 0·28 per cent. per 1° F. (0·51 per cent. per 1° C.) for a rail 15·9 microhms per 100 lb. yard to 0·24 per cent. per 1° F. (0·43 per cent. per 1° C.) for a rail 20·5 microhms per 100 lb. yard. Therefore taking the extreme case of a rail of 16 microhms per 100 lb. yard tested at 40° F. (4°·5 C.) or 80° F. (27° C.) the use of the mean temperature coefficient may introduce an error of ± 0·6 per cent. For a smaller range of temperature the error would be proportionately less.

Reduction Factors.

Reduction factors for converting the resistance of a rail of known weight measured at a given temperature to its value in terms of the Standard (microhms per 100 lb. yard at 60° F.) are given in Tables I. and II.

To express the resistance of a rail of known weight, as found by observation at any temperature, in terms of the Standard value (microhms per 100 lbs. yard at 60° F.), multiply the observed resistance expressed in microhms per yard by the factor given in the Table appropriate to the weight of the rail in lbs. per yard and to the temperature at which the observation is made.

TABLE I.

FAHRENHEIT REDUCTION FACTORS.

Weight of Rail: lbs. per yd.	40° F.	42° F.	44° F.	46° F.	48° F.	50° F.	52° F.	54° F.	56° F.	58° F.	60° F.	62° F.	64° F.	66° F.	68° F.	70° F.	72° F.	74° F.	76° F.	78° F.	80° F.
20	·2110	·2098	·2087	·2076	·2064	·2053	·2042	·2032	·2021	·2010	·200	·1990	·1979	·1969	·1959	·1949	·1939	·1930	1920	·1911	·1901
25	·2637	·2623	·2608	·2594	·2580	·2567	·2553	·2540	·2526	·2513	·250	·2487	·2474	·2462	·2449	·2437	·2424	2412	2400	·2388	·2376
30	·3164	·3147	·3130	·3113	·3097	·3080	·3064	·3048	·3031	·3016	·300	·2984	·2969	·2954	·2939	·2924	·2909	·2895	·2880	·2866	·2852
35	·3692	·3672	·3652	·3632	·3613	·3593	·3574	·3555	·3537	·3518	·350	·3482	·3464	·3446	·3429	·3411	·3394	3377	3360	·3343	·3327
40	·4219	·4196	·4174	·4151	·4129	·4107	·4085	·4063	4042	·4021	·400	3979	·3959	3938	·3918	3899	·3879	3860	3840	·3821	·3802
45	·4747	·4721	·4695	·4670	·4645	·4620	·4596	·4571	·4547	·4523	·450	·4477	·4454	·4431	·4408	·4386	·4364	·4342	·4320	·4299	·4278
50	·527	·525	·522	·519	·516	·513	·511	·508	·505	·503	·500	·497	·495	·492	·490	·487	·485	·482	·480	·478	·475
55	·580	·577	·574	·571	·568	·565	·562	·559	·556	·553	·550	·547	·544	·541	·539	·536	·533	·531	·528	·525	·523
60	·633	·629	·626	·623	·619	·616	·613	·609	·606	·603	·600	·597	·594	·591	·588	·585	·582	·579	·576	·573	·570
65	·686	·682	·678	·675	·671	·667	·664	·660	·657	·653	·650	·647	·643	·640	·637	·634	·630	·627	·624	·621	·618
70	·738	·734	·730	·726	·722	·719	·715	·711	·707	·704	·700	·696	·693	·689	·686	·682	·679	·675	·672	·669	·665
75	·791	·787	·783	·778	·774	·770	·766	·762	·758	·754	·750	·746	·742	·738	·735	·731	·727	·724	·720	·716	·713
80	·844	·839	·835	·830	·826	·821	·817	·813	·808	·804	·800	·796	·792	·788	784	·780	·776	·772	·768	·764	·760
85	·897	·892	·887	·882	877	·873	·868	·863	·859	·854	·850	·846	841	·837	·833	·828	·824	·820	·816	·812	·808
90	·949	·944	·939	·934	·929	·924	·919	·914	·909	·905	·900	·895	·891	·886	·882	·877	·873	·868	·864	·860	·855
95	1·002	·997	·991	·986	·981	·975	·970	·965	·960	·955	·950	·945	·940	·935	·931	·926	·921	·917	·912	·908	·903
100	1·055	1·049	1·043	1·038	1·032	1·027	1·021	1·016	1·010	1·005	1·000	·995	·990	·985	·980	·975	·970	·965	·960	·955	·951
105	1·108	1·101	1·096	1·090	1·084	1·078	1·072	1·067	1·061	1·055	1·050	1·045	1·039	1·034	1·029	1·023	1·018	1·013	1·008	1·003	·998
110	1·160	1·154	1·148	1·142	1·135	1·129	1·123	1·117	1·112	1·106	1·100	1·094	1·089	1·083	1·078	1·072	1·067	1·061	1·056	1·051	1·046
115	1·213	1·206	1·200	1·193	1·187	1·181	1·174	1·168	1·162	1 156	1·150	1·144	1·138	1·132	1·127	1·121	1·115	1·110	1·104	1·099	1·093
120	1·266	1·259	1·252	1·245	1·239	1·232	1·225	1·219	1·213	1·206	1·200	1 194	1·188	1·182	1·175	1·170	1·164	1·158	1·152	1·146	1·141

TABLE II.

CENTIGRADE REDUCTION FACTORS.

Weight of Rail : lbs. per yd.	5° C.	6° C.	7° C.	8° C.	9° C.	10° C.	11° C.	12° C.	13° C.	14° C.	15° C.	15·6° C.	16° C.	17° C.	18° C.	19° C.	20° C.	21° C.	22° C.	23° C.	24° C.	25° C.
20	·2105	·2094	·2084	·2074	·2064	·2054	·2044	·2034	·2025	·2015	·2006	·200	·1996	·1987	·1978	·1968	·1959	·1950	·1942	·1933	·1924	·1915
25	·2631	·2618	·2605	·2593	·2580	·2567	·2555	·2543	·2531	·2519	·2507	·250	·2495	·2484	·2472	·2461	·2449	·2438	·2427	·2416	·2405	·2394
30	·3157	·3142	·3126	·3111	·3096	·3081	·3066	·3052	·3037	·3023	·3008	·300	·2994	·2980	·2966	·2953	·2939	·2926	·2912	·2899	·2886	·2873
35	·3683	·3665	·3647	·3630	·3612	·3594	·3577	·3560	·3543	·3526	·3510	·350	·3493	·3477	·3461	·3445	·3429	·3413	·3398	·3382	·3367	·3352
40	·4210	·4189	·4168	·4148	·4128	·4108	·4088	·4069	·4049	·4030	·4011	·400	·3992	·3974	·3955	·3937	·3919	·3901	·3883	·3865	·3848	·3831
45	·4736	·4713	·4689	·4667	·4644	·4622	·4599	·4577	·4556	·4534	·4513	·450	·4491	·4470	·4450	·4429	·4409	·4389	·4369	·4349	·4329	·4310
50	·526	·524	·521	·518	·516	·513	·511	·509	·506	·504	·501	·500	·499	·497	·494	·492	·490	·488	·485	·483	·481	·479
55	·579	·576	·573	·570	·568	·565	·562	·560	·557	·554	·552	·550	·549	·546	·544	·541	·539	·536	·534	·531	·529	·527
60	·631	·628	·625	·622	·619	·616	·613	·610	·607	·605	·602	·600	·599	·596	·593	·590	·588	·585	·582	·580	·577	·575
65	·684	·681	·677	·674	·671	·667	·664	·661	·658	·655	·652	·650	·649	·646	·643	·640	·637	·634	·631	·628	·625	·622
70	·737	·733	·729	·726	·722	·719	·715	·712	·709	·705	·702	·700	·699	·695	·692	·689	·686	·683	·680	·676	·673	·670
75	·789	·785	·782	·778	·774	·770	·767	·763	·759	·756	·752	·750	·749	·745	·742	·738	·735	·731	·728	·725	·721	·718
80	·842	·838	·834	·830	·826	·822	·818	·814	·810	·806	·802	·800	·798	·795	·791	·787	·784	·780	·777	·773	·770	·766
85	·894	·890	·886	·881	·877	·873	·869	·865	·860	·856	·852	·850	·848	·844	·840	·837	·833	·829	·825	·821	·818	·814
90	·947	·942	·938	·933	·929	·924	·920	·915	·911	·907	·903	·900	·898	·894	·890	·886	·882	·878	·874	·870	·866	·862
95	1·000	·995	·990	·985	·980	·976	·971	·966	·962	·957	·953	·950	·948	·944	·939	·935	·931	·926	·922	·918	·914	·910
100	1·052	1·047	1·042	1·037	1·032	1·027	1·022	1·017	1·012	1·008	1·003	1·000	·998	·993	·989	·984	·980	·975	·971	·966	·962	·958
105	1·105	1·100	1·094	1·089	1·084	1·078	1·073	1·068	1·063	1·058	1·053	1·050	1·048	1·043	1·038	1·033	1·029	1·024	1·019	1·015	1·010	1·006
110	1·158	1·152	1·146	1·141	1·135	1·130	1·124	1·119	1·114	1·108	1·103	1·100	1·098	1·093	1·088	1·083	1·078	1·073	1·068	1·063	1·058	1·053
115	1·210	1·204	1·198	1·193	1·187	1·181	1·175	1·170	1·164	1·159	1·153	1·150	1·148	1·142	1·137	1·132	1·127	1·121	1·116	1·111	1·106	1·101
120	1·263	1·257	1·250	1·244	1·238	1·232	1·226	1·221	1·215	1·209	1·203	1·200	1·198	1·192	1·187	1·181	1·176	1·170	1·165	1·160	1·154	1·149

NOTE.—Where the weight of the rail in lbs. per yard differs from the specified weight by an appreciable amount a correction should be made. The result found from the Table by the use of the specified weight should be multiplied by the ratio of the actual weight to the specified weight, *e.g.*, in the case of an 80 lb. rail which is actually found to weigh 81 lbs. per yard, the observed resistance should be multiplied by $\frac{81}{80}$ before applying the factor given in the Table which corresponds to an 80 lb. rail at the actual temperature of the observation.

APPENDIX I.

In order that previous values for the resistance of rails in terms of copper, usually expressed either as "Relative Mass Resistivity," "Relative Volume Resistivity," or as a "Relative percentage Conductivity" may be readily reduced to values in terms of the Standard Method, the following reduction formulæ have been prepared :—

REDUCTION FORMULÆ.

Resistivity and Conductivity in terms of Standard Copper.

The resistivity of a rail in terms of Standard copper is found from that in microhms per 100 lb. yard by the following formulæ :—

Relative Mass Resistivity = 0·360 (microhms per 100 lb. yard).

Relative Volume Resistivity = 0·408 (microhms per 100 lb yard).

Or, inverting these formulæ :—

$$\text{Microhms per 100 lb. yard} \quad \begin{cases} = 2{\cdot}778 \text{ (Relative Mass Resistivity).} \\ = 2{\cdot}45 \text{ (Relative Volume Resistivity).} \end{cases}$$

The Relative percentage Conductivity of a rail in terms of Standard copper is found from the resistance in microhms per 100 lb. yard by the following formulæ :—

$$\text{Relative percentage Mass Conductivity} = \frac{277{\cdot}8}{\text{microhms per 100 lb. yard.}}$$

$$\text{Relative percentage Volume Conductivity} = \frac{245}{\text{microhms per 100 lb. yard.}}$$

and inversely : —

$$\text{Microhms per 100 lb. yard} = \frac{277{\cdot}8}{\text{Relative percentage Mass Conductivity.}}$$

$$\text{Microhms per 100 lb. yard} = \frac{245}{\text{Relative percentage Volume Conductivity.}}$$

Thus a rail having a resistance of 18·0 microhms per 100 lb. yard will have a Relative Mass Resistivity in terms of Standard copper of 18 × 0·360 or 6·48, and a Relative Volume Resistivity of 18 × 0·408 or 7·34. The Relative percentage Mass Conductivity of the same rail would be $\frac{277 \cdot 8}{18} = 15 \cdot 43$ per cent. and the Relative percentage Volume Conductivity $\frac{245}{18} = 13 \cdot 6$ per cent.

In accordance with the International Standard of Resistance for Copper* it is here assumed that the resistance of a copper wire 1 metre in length weighing 1 gramme is 0·15065 ohms at a temperature of 60° F. (15°·6 C.).

For the purposes of the above calculations, the following densities have been adopted:—

Density of Steel = 7·84 grammes per cubic centimetre.
= 489·4 lbs. per cubic foot.

Density of Copper = 8·89 grammes per cubic centimetre.
= 555 lbs. per cubic foot.

Thus the ratio of the density of copper to the density of steel has been taken as 1·134. It should be noted, however, that conductor rails vary appreciably in density, and it may be necessary in certain cases to correct for this fact.

Resistance per yard of a Rail 1 square inch in area of cross-section.

According to the above figures, the area of the cross-section of a 100 lb. steel rail is 9·81 square inches. Hence, if R be the resistance of a rail in microhms per 100 lb. yard, that of a rail of the same material 1 yard long 1 square inch in area is 9·81 × R.

Taking, as before, as an example a rail having a resistance of 18 microhms per 100 lb. yard, that of a rail of the same material 1 square inch in sectional area is 18 × 9·81 or 176·6 microhms.

Resistance in Metric Units.

The following formulæ serve to connect the values for the resistance of steel rails in British and Metric Units:—

Microhms per metre-kilogramme
= 54·2 × microhms per 100 lb. yard.

Microhms per metre sq. cm.
= 69·2 × microhms per 100 lb. yard.

Adopted by the International Electrotechnical Commission at Berlin, September, 1913 (see Publication 28 of the I.E.C.)

Thus, for a rail having a resistance of 18 microhms per 100 lb. yard, we find :—

Resistance of 1 metre weighing 1 kilogramme
= 976 microhms.

Resistance of 1 metre 1 sq. cm. in section
= 1,246 microhms.

NOTE.—The following figures for Copper and for Steel may be of service :—

Copper.

Standard Annealed Copper at 20° C.

International Standard Resistance per Metre gramme = 0·15328...ohm.

Standard Annealed Copper at 60° F. (15°·6 C.) calculated from the International Standard.

100 lb. yard—Area of cross section	...	8·65 sq. ins.	
Resistance per metre gramme ...	...	0·15065 ohm.	
ditto 100 lb. yard ...	...	2·777 microhms.	
ditto centimetre cube ..	...	1·694	„
ditto inch cube ...	...	0·667	„
ditto 1 yard, 1 sq. in. section...		24·01	„

Steel.

100 lb. yard—Area of cross section = 9·81 sq. ins. Taking a rail having a resistance of 18 microhms per 100 lb. yard—

$$\text{Resistance per cm. cube} = \frac{18 \times 9{\cdot}81 \times 2{\cdot}54}{36} = 12{\cdot}46 \text{ microhms.}$$

$$\text{„ „ inch cube} = \frac{18 \times 9{\cdot}81}{36} = 4{\cdot}90 \text{ microhms.}$$

1 yard, 1 sq. in. section = 18 × 9·81 = 176·6 microhms.

APPENDIX II.

(*a*) Observations on a large number of flat bottom conductor rails, carried out at the National Physical Laboratory, have shown that the resistance of rails now in use, measured as specified in this Report, ranges between 15 and 19·5 microhms: the mean value obtained for 44 samples was 18·0 microhms. In the case of a number of specially hard rails of T section, the values found for 14 samples varied from 19·8 to 20·5 microhms, the mean being 20·2 microhms.

(*b*) The following Table gives the relation between the resistance temperature coefficient, and composition of some samples tested at the National Physical Laboratory for the purpose of this Report :—

RESISTANCE, TEMPERATURE COEFFICIENT AND CHEMICAL ANALYSES OF STEEL RAILS, ETC.

Sample.	Microhms per 100 lb. yard.	Relative Resistivity.		Temp. Coefft. % for 1° C.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Arsenic.	Copper.	Nickel.	Chromium.
		Mass.	Volume.										
1	13·9	5·00	5·67	0·55	—	—	—	—	—	—	—	—	—
2	15·9	5·72	6·48	0·51	0·040	Trace	0·044	0·035	0·165	0·03	0·025	0·047	Trace
3	16·9	6·08	6·89	0·47	0·035	0·011	0·076	0·017	0·100	0·028	0·0048	0·330	Trace
4	18·35	6·59	7·47	0·45	0·092	Trace	0·097	0·072	0·362	0·065	0·046	0·094	Trace
5	20·5	7·38	8·37	0·43	0·403	Trace	0·060	0·027	0·365	0·012	0·048	0·081	Trace
6	25·3	9·1	10·3	0·35	0·561	0·068	0·028	0·066	0·605	0·021	—	—	—

Of these, sample No. 1 is electrolytic iron and No. 6 is a piece of ordinary running rail. Samples 2, 3, 4 and 5 only are conductor rails.

Temperature Coefficient.

The mean temperature coefficient of the four conductor rails is 0·26 per cent. per 1° F. (0·47 per cent. per 1° C.). If this coefficient be taken, the error in calculating the resistance of any rail within the range of 16 to 20 microhms per 100 lb. yard, over a range of temperature of from 60° F. to 32° F. (15°·6 C. to 0° C.) or from 60° F. to 104° F. (15°·6 C. to 40° C.) would not exceed one per cent. For a smaller range the possible error would be proportionately less.

British Engineering Standards Association.

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